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SIMULATION-BASED DESIGN PRACTISE USED IN FINNISH MOBILE WORKING MACHINES INDUSTRY

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1 Introduction

The virtual prototyping tools have developed rapidly during the past decade. These tools have been applied in many different mobile work machines as follows: mining and construction machinery, mobile rock crushers, fire and rescue platforms and mini loaders. Implementing virtual prototyping technology in mobile working machines is going to increase in the upcoming years because tests by using physical prototypes are expensive and time demanding. It will be important to know how the mobile working machine industry is expecting to implement the new technology especially for the system and component developers and suppliers.

The intelligence of machines will increasingly grow in the future. The simulation is needed to test how intelligence works in all environments and use cases. Good design practice with understanding of manufacturing, implementing more intelligence in machines, adapting manufacturing networks and simultaneous design practice will give opportunities to increase competitiveness.

2 Background

In the early 1960s, Ivan Sutherland developed the SKETCHPAD system [1], a milestone of research achievement in computer graphics. The evolution of computer graphics has since resulted in the development of Computer Aided Design (CAD). Early CAD systems were essentially for two-dimensional drawing and drafting. Solid modelling techniques emerged to describe three-dimensional products unambiguously [2], and it has since seen an increase in solid modellers and three-dimensional CAD systems. Product development community has waited since 1980’s an integrated computerised tool for supporting synthesis and analysis phases of engineering design. Today, it seems that CAD tools support 3D modelling, FEM analysis, analysis of kinematics chains, man-machine interactions, and manufacturing and assembly studies. These tools are called virtual prototyping tools.

The virtual prototyping assists in efficient and customer oriented product development, user friendly product, producing maximum value to the customer, and creating value adding services. In the view of virtual prototyping technologies, the strategy can include functions such as strengthening the connections with business operation and product development, up-to-date interactive and efficient product development, custom-oriented product development, optimal utilisation of product and value-added life-cycle approach.

3 Objectives

Objectives of the research was to find out the product development process currently used in the globally leading mobile working machines industry and especially study if that process support the use of virtual prototyping tools. Based on review and industrial cooperation projects our aim is to suggest how and where increasing the utilisation of virtual prototyping tools in the product development process.

4 Research method

The research studied different theoretical product development models with a standardised IDEF0-flowchart [3] and composed a synthesis model, which represents the product development process of mobile working machines companies. The developed synthesis model is based on interviews with experts in five globally operating mobile working machines companies during spring 2003 [4]. Global market share of these companies varies from 15% to 70%.

The IDEF0-flowchart used for modelling all of the product processes in this research is a standardised, purpose-built tool for modelling decisions, functions and actions in an organisation or a system. The models are very straightforward and, therefore, they are usually interpreted correctly even without prior knowledge of the IDEF0. The IDEF0 models use a very limited amount of symbols and, with the decomposition technique, they can be focused to a suitable level of detail.

The two primary modelling components are functions (represented in a diagram by boxes) and the data and objects that interrelate those functions (represented by arrows). Each side of the function box has a standard meaning in terms of box/arrow relationships. The arrows may represent inputs, outputs, controls, mechanisms or calls to other processes (Figure 1).

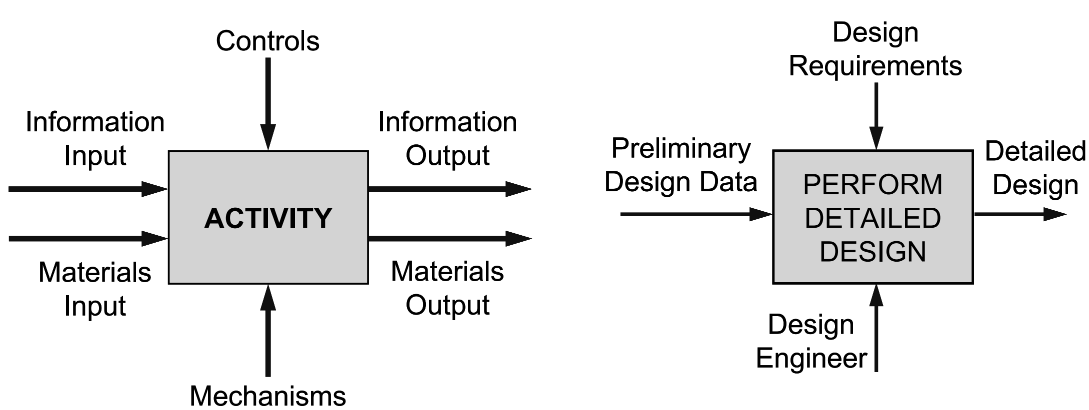

Figure 1. The basic concept of IDEF0-method. On the right is an example of IDEF0.

Every IDEF0 sheet may contain between three and six functions and every function can be decomposed to its own sheet as a new sub process. Decomposition can be continued until the subject is described at a level necessary to support the goals of a particular project. Therefore, the same model can be shown at a very detailed level or with a more general view to give a good overall understanding of the modelled process. In this research, the models were usually modelled down to the third level from the main diagram.

Parallel with composing the synthesis model company interviews were carried out and reported in [5]. A summary of the topics that were discussed during the interviews is given in Table 1.

Table 1. Examples of questions in the interview.

Product architecture in terms of modelling and simulation activities
How is the product divided into subsystems and which of them are designed in-house?
Does the design and development of these subsystems involve modelling and simulation?
In which level products are simulated (the whole product or some of the subsystems)?
The main challenges
What are the problems of modelling and simulating subsystems in general?
What is the most time consuming phase in modelling and simulating subsystems (acquisition of parameter values, modelling, simulation, verification, post processing)?
The future visions in modelling and simulation
What kind of software improvements there should be?
What kind of improvements there should be in modelling methods?
What kind of improvements there should be in simulation methods?

5 Results

The product process used in industry is divided into six phases (Figure 2). The first stage is the business process where business cases are investigated and technology development processes or product design processes start. In a technology development process, new technologies and components are researched and the technology information collected in this phase is transferred to the first stage of the product development process, the conceptualisation, or back to the business process as information.

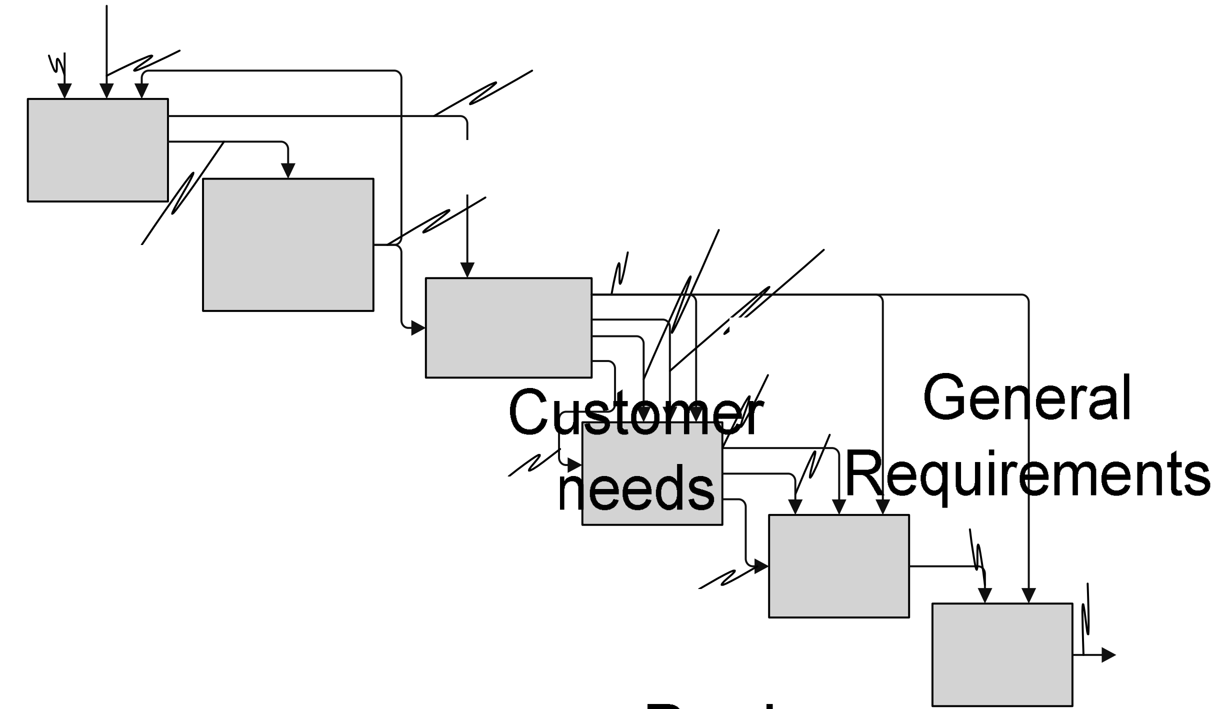

Figure 2. The overall product process used in industry is divided into six phases.

In the conceptualisation phase, the preliminary 3D-CAD model of the product is created and the first simulation tests are carried out (Figure 3).

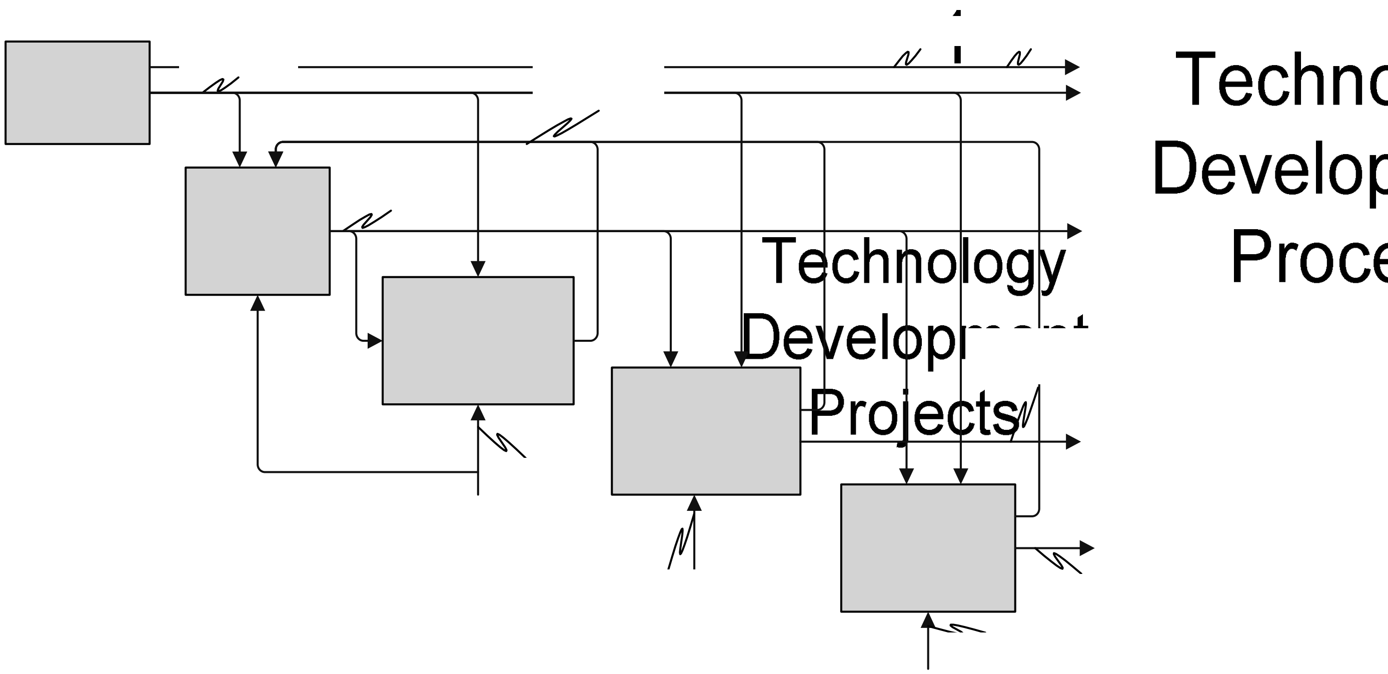

Figure 3. The conceptualisation phase is divided into five phases.

The principal solution of the product is outlined by making the simple 3D models and preliminary dynamic and structural analyses. The load information needed in the structural analyses is obtained as the results of dynamic analyses. The concept sharpens up iterating between modelling and the analyses to the level in which the coarse 3D model exists from the product. In the model there are all components and subsystems which are essential from the point of view of the functionality but the details like chamfers have not been designed. In a very iterative manner, the concept is finalised and the product design stage begins.

In the product design phase (Figure 4), the preliminary CAD-models are detailed with iterative cycles of simulation, tests and redesigning. All the parts and components are designed in detail iterating between the 3D modelling and dynamic and structural analyses. The building of the prototypes of the whole product or its part or of different mock-up models is begun when the design of the product has proceeded to a sufficient level to build the models in question.

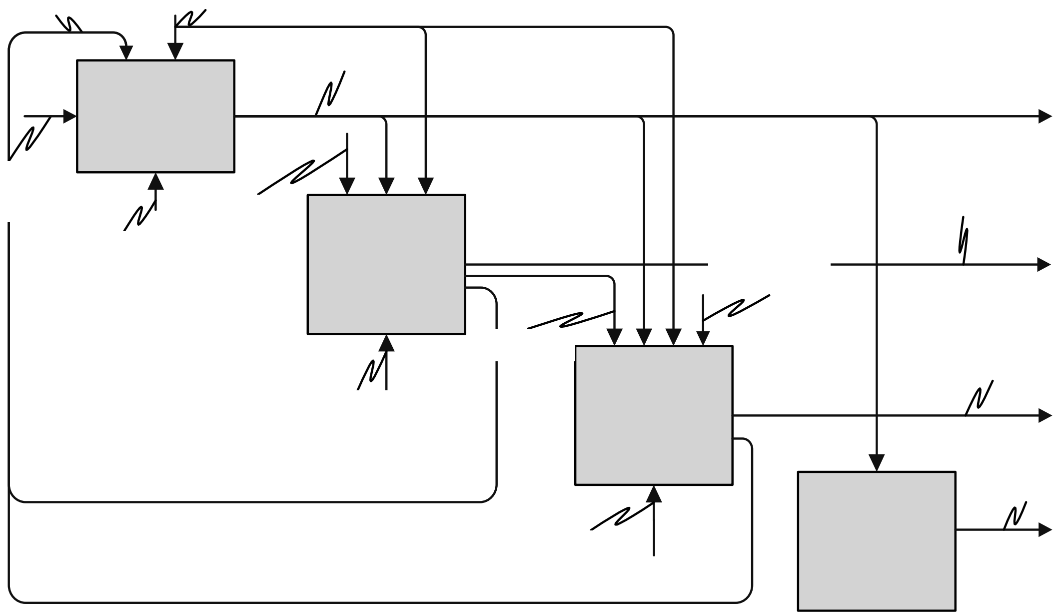

Figure 4. The product design phase.

After suitable results have been obtained from the tests, the simulations are verified by the means of prototype tests (Figure 5).

The tests are performed according to the testing plan. The purpose of tests is to make sure that the product meets the demands of the specification for example operating characteristics, serviceability and performance. The results of prototype tests are compared with the results of analyses that have been done at the product design stage. If there are significant differences between the real tests and the analysis results, the input parameters of analysis methods or methods themselves has to be explored for future needs. The design errors that have been perceived in the prototype tests are corrected, the necessary parts or components are designed again and the changes are updated to 3D model. Prototype tests are carried out with the renewed parts in the necessary scope. Redesign and testing are performed until the demands of the product specification will be met.

Changes, specifications

Product Specificati

The necessary changes for the product are made and production is ramped up. The verification results are also used to update the simulation tools to make them more accurate.

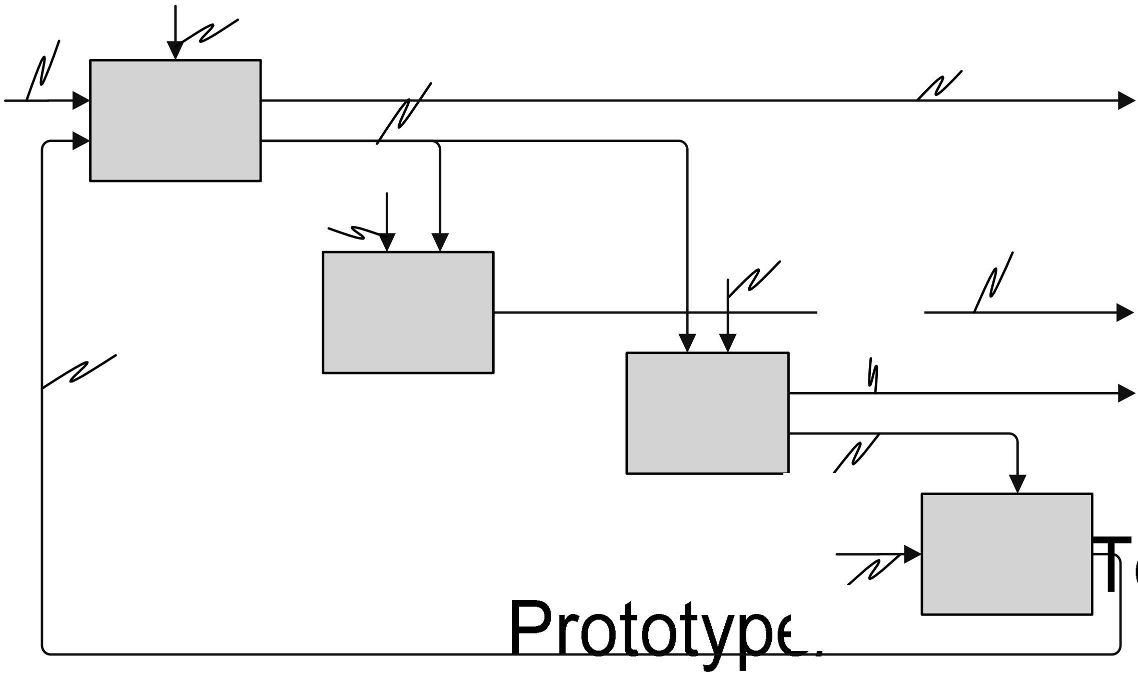

Figure 5. After suitable results have been obtained from the tests, the simulations are verified by the means of prototype tests.

The following major topics could be extracted from the interview material [5]. As a trend there is need for using simulation technology in the early phases of design (Figure 6).

The functional demands of products have tightened so an efficient product development process is needed with new methods and tools. Companies which use simulations already at an early stage in the product development process have been able to accelerate time-to-market. The use of product simulations increases the know-how of the product development team and helps to understand the reasons for the design decisions.

The division of the model to subsystems from simulation point of view requires experience. On the other hand, the simple model is satisfactory, on the other hand a more exact model is required. Likewise the acquisition of parameters to certain simulation models is difficult.

The control of the versions of the simulation model is difficult and also support for simulation data exchange is very limited. There is a need to exchange product data between 3D modelling, FEM, real-time simulation and multi-body dynamics software. At the moment it lacks interoperability between these tools. An important requirement is also possibility to distribute simulation models easily between design teams either locally or globally.

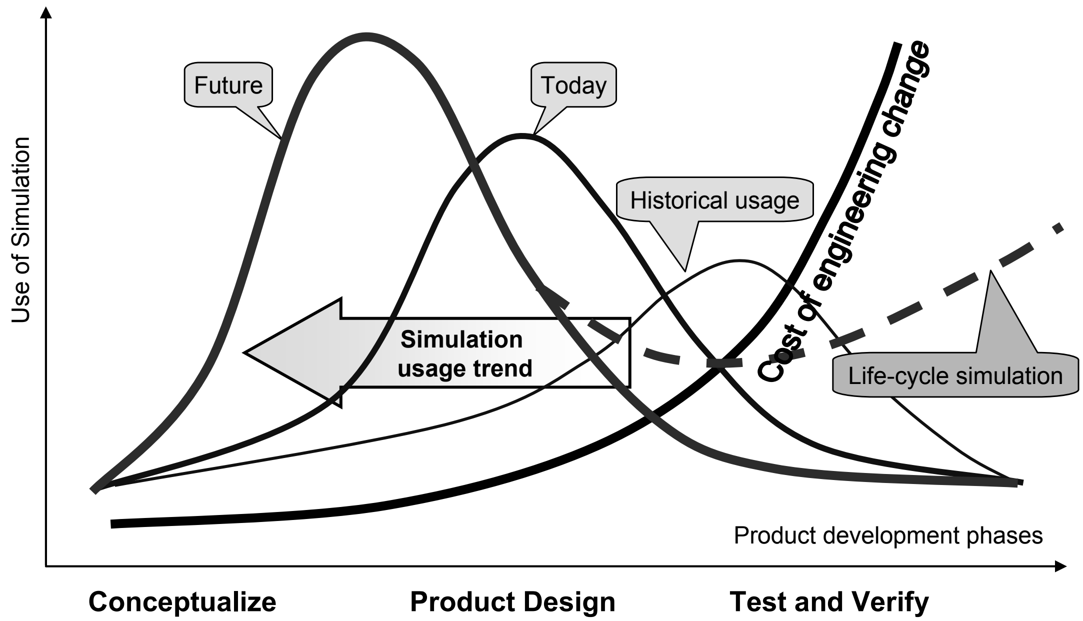

Figure 6. The simulations have been utilised traditionally in the end the product development stage mainly to verify that the product meets the demands. Nowadays many companies simulate the subsections of the product at the product design stage. Where would the companies like to go, the use of modelling and the simulation already at a stage in which with a real-time digital prototype is tested reactions of the lead-users (lead-user is a user who tend to face needs that will be in the market place, months or years in advance of other users).

6 Discussion

There are big differences between the product development theories and the synthesis model, i.e., current way of action. The biggest difference is noticed before the product development itself starts. The companies use much more effort to managing their product portfolios. Business cases are studied very carefully and only the most promising projects are funded. The second stage after the business case is researching and developing new relevant technologies, methods and tools to be used in the future products. In this phase both simulation software and prototype test are used. Strong emphasis on technology development stage might be a result from the cooperation what companies have made in technology development programs in Europe and in Finland.

The conceptual design and the embodiment design stages are much more iterative than ones in theoretical models. Design solutions are found with the aid of simulation tools and 3D-CAD-systems by active probe-and-learn type of design, instead of using the methods like establishing function structures and searching for solution principles that are the key concept of Engineering Design by Pahl and Beitz [6] and also other product development theories [7,8,10,11]. In general there is shift from traditional way of using simulation as a verification tool to use simulation for studying different design alternatives (Figure 7). The simulation of the product is a visual and powerful way to add the understanding of the behaviour of the product.

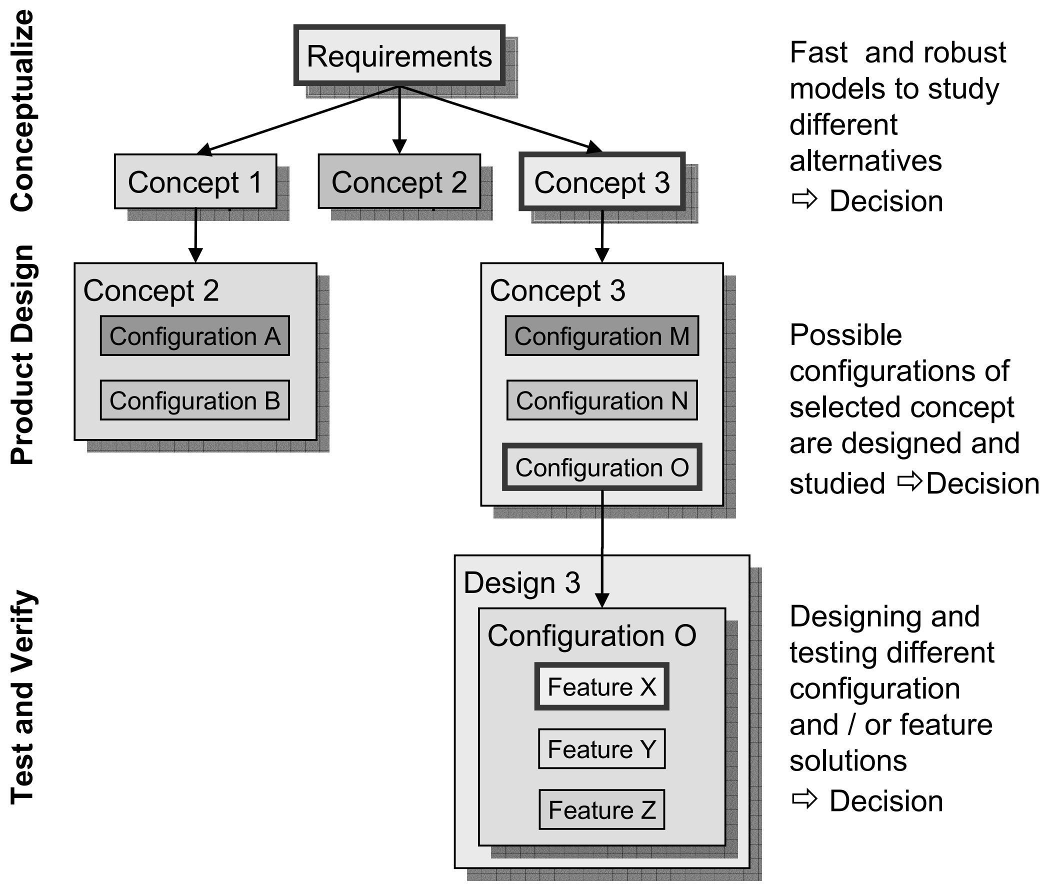

Figure 7. Different design alternatives are studying and testing using simulation.

It was noticed that it is not sufficient to just view and share 2D-drawings. Especially, when in most cases the 2D-drawings are not available in the PDM-system until the design is almost ready for production. In that case, the possible changes for the designs are much more expensive to make than in the earlier stages of product development. Instead, it is important to share 3D-models because companies use a 3D-CAD and PDM-based concurrent engineering method in product development [9]. An example of using a commercial tool for assembly simulation purposes is shown in Figure 8. Another example comes from a leading provider of heavy-duty material handling equipment. In a development project, a commercial, advanced CAD-system and its FEM package was used to analyse the structure of the whole machine. Based on analysis and simulation, it was possible to reduce the weight of machine by 10%.

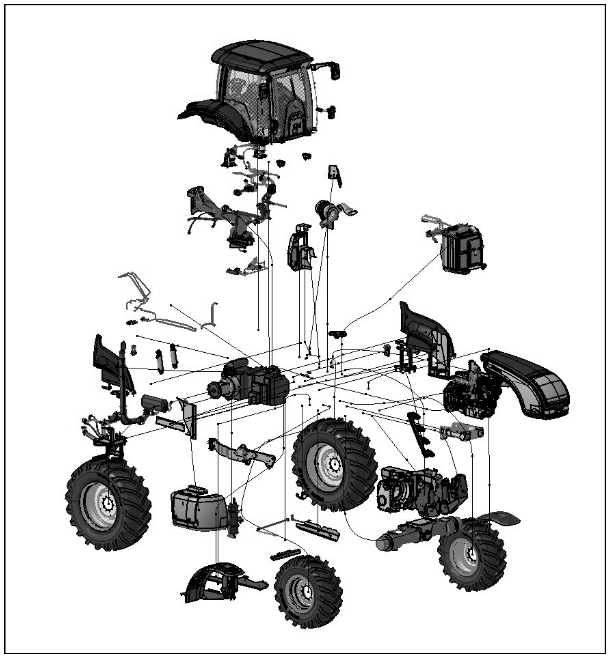

Figure 8. 3D-model of a commercial CAD-system offers good possibilities to make assembly simulations.

In a simulation-based design process, the importance of the efficient order of development tasks is crucial. In particular, the 3D-model is used as the starting point in many simulation tools. When the design process proceeds, the product model develops and the different simulation tools produce different simulation models. The PDM-system maintains different versions so that the simulations will always be performed with the right product version. The development of the product model and simulation models at the separate stages of the product process is shown in Figure 9.

Simulation-based design practice could support the development of design process of mobile working machines and vehicles in following sectors:

- Strengthening product development by supporting decisions in product development, by enhancing the evaluation of the costs in product development and production, seamless information exchange with partners and suppliers.

- More efficient knowledge management and enhanced evaluation methods.

- Value creating life-cycle approach – enhancing the life-time functionality and reliability of a machine, simplifying maintenance, and applying environmental and sustainable development approach.

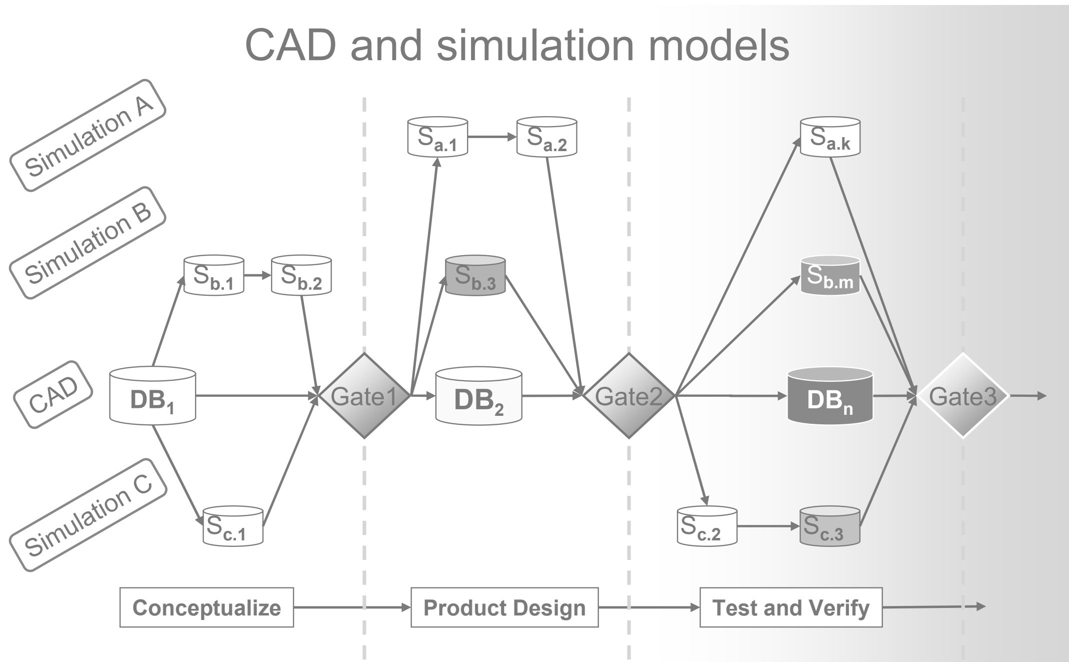

Figure 9. CAD and simulation models. Gates show the decision phases of the product process in which the progress of the project is checked and a decision is made on the continuation. The development of the product model is described by DB1, DB2, DBn, and the development of the simulation models conducted from the product model.

7 Conclusion

The increasing speed of product development processes, as well as the fact that product development responsibility is more and more divided between sub-contractors and partners, increases the importance of well-defined product development process models. The product development process should define all of the necessary breakpoints where the project is evaluated according to defined criteria. A defined glossary is required to avoid misunderstandings between the partners involved in the project.

In this research, it was discovered that IDEF0 modelling of Product Development processes offers a good visual aid to discuss the stages and milestones of processes. Modelling also offered a good basis to discover actual processes from industry. Based on this research we are able to cooperate with companies and suggest where they could utilise simulation for harvesting benefits. Modelling also offers possibilities to manage re-use of simulations.

Product Development processes are influenced by computerised 3D modelling, simulation, analysis and virtual prototyping. The technology development phase and studying the business case have great significance in the product development process used today. Therefore, more powerful tools, like different simulation tools, especially real-time simulation tools, should be developed to support these phases. In general mechanical system simulation has proved its potential and it has established its position as an effective development tool.

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